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LASER VELOCIMETER DEVELOPMENTS FOR SURVEYING THIN BOUNDARY LAYERS IN A MACH 6 HIGH REYNOLDS NUMBER FLOW

Experimental Engineering Branch
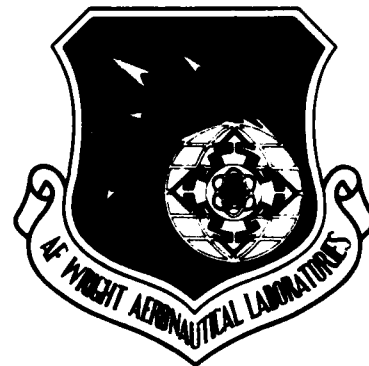Aeromechanics Division

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Final Technical Report for Period June 1981 to December 1981

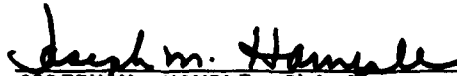Approved for public release; distribution unlimited

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The technical report has been reviewed and is approved for publication.

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Two-component fringe-counter type laser velocimeter techniques were developed to measure model boundary layer velocity profiles in a Mach 6 High Reynolds Number Wind Tunnel. Free stream velocities were approximately 3500 feet per second. Boundary layers as thin as 0.20 inches were surveyed to within .007 inches of the surface of a 16 inch wide sharp leading edge flat plate. Optical, signal processing, and computational techniques and equipment are discussed. Artificial flow field seeding of 1.0 to 2.0 micron particles was achieved in the facility

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20. Abstract (Continued)

stagnation section. This test program was conducted at stagnation pressures of 700 and 1400 psia. The stagnation temperature for the entire program was 1100°R. Data rates of 2,000 per second were realized through the velocimeter test volume. A three-axis computer-controlled traversing system provided .0001 inch survey repeatability and position accuracy of .0001 inch/inch of travel. Sample boundary layer velocity profiles are shown at two axial stations on the surface of the flat plate and at its intersection with an aft mounted 30° ramp. Turbulence and the cross correlation function plots are also presented for the latter case.

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FOREWORD

This report describes in-house laser velocimetry developments for
obtaining boundary layer profiles on flat model surfaces in high speed
high Reynolds number flows. The facility testing was accomplished in the
Mach 6 High Reynolds Number Facility of the Flight Dynamics Laboratory
(FDL) during the period of June to December 1981. The development effort
was conducted under work unit 24041307, "Development of Testing
Techniques and Aero-Optical Diagnostics to Advance Aerodynamic Ground
Simulation" of task 240413, "Aerodynamic Ground Test Technology".

This report was prepared by Messrs Daniel M. Parobek and Clifford B.
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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

The theory and general techniques of laser velocimeters (LVs) are
well known and described in the literature (References 1 through 4).
Applications have been concentrated on the subsonic through supersonic
flow regimes. However, little work has been carried out at Mach numbers
of six or above except in limited or special cases such as hypersonic
helium - particle flows (Reference 5). The objective of the work
described in this report is to develop the technology to map velocity
profiles through very thin boundary layers of flat surfaces in a Mach 6
flow. This work is in support of in-house boundary layer research. This
development and required wind tunnel tests were accomplished in the
Flight Dynamics Laboratory (FDL) Mach 6 High Reynolds Number Facility
which operates in a blowdown mode.

The problems identified at the beginning of the development could be
characterized as a need for obtaining data extremely close to a wide flat
surface, the need to develop seeding techniques for 2,100 psia operation
at air temperatures up to 850°F, and the need for rapid data acquisition
due to limited facility run time and flow velocities over 3,000 feet per
second. An existing three-color, three-component Fringe-Counter type LV
system was used for this program. This system had been previously
developed at FDL for in-house testing in subsonic through hypersonic
flows in tunnels ranging from 8" to 2' width test sections. Figure 1
shows the optical system configured in the original three-component
backscatter mode. The optics were rearranged for forward scatter in this
test series to improve signal levels. As this report develops, it will
become obvious that the compromise design of the original LV caused
problems in coping with the high velocities and velocity gradients in the
Mach 6 boundary layer flows. This report not only presents workable
solutions to the above-mentioned constraints and problems but further
exposes additional problems as testing progressed. Fortunately,
solutions for most of these have been implemented. This report presents
a nominal amount of test data to illustrate levels of achievement.

SECTION II

APPARATUS

1. MACH 6 TUNNEL AND TEST MODEL

The wind tunnel (Reference 6) is an open jet blowdown facility with a nozzle exit diameter of 12.3 inches (shown in Figure 2a). Free stream velocity is over 3,000 feet per second. Typical runs range from several seconds to ten minutes. High pressure air from a bottle farm is heated to $1100^{\circ}R$ by means of two electrical resistance heaters which in turn heat a stainless steel ball storage bed. The stagnation temperature is constantly monitored and tunnel running is discontinued when T_0 drops below $1050^{\circ}R$. Although the stagnation pressure is variable between 700 and 2100 psia, most of the data in this test series was taken at $P_0 = 700$ psia. The flat plate model used in this LV test is shown installed in the facility in Figure 2b. The plate is shown with a trailing edge ramp of 30° which was used for a portion of the test. The ramp strakes in the photograph were not used in this program. Testing is initiated by establishing the tunnel flow field and then injecting the model into the flow. The plate surface is 16 inches wide at the LV survey stations. Boundary layer surveys were made on the longitudinal center line of the model.

2. LASER VELOCIMETER OPTICAL SYSTEM

The LV optical system consisted of a 4 watt Argon Ion laser and modular optics. The optical path for the two component forward scattering arrangement is shown in Figure 3. The transmitting optics are mounted on a three-axis positioning table. The laser output is collimated to a 1 mm diameter to assure that the beam waist and intersection are in the same spatial location. The beam is passed through a polarization cube and rotator to enable beam attenuation without laser output adjustments and to assure the beam has the correct polarization. The beam is then dispersed into its component wavelengths by means of Brewster angle prisms. The separated beams are then directed

through the optical system by dielectric mirrors. First the blue beam (λ = 488.0) is polarized horizontally and split to a 50mm separation vertically. Then the green beam (λ = 514.5nm) is displaced and polarized vertically before it is split horizontally to a 50mm separation. The blue beams are then passed through a single Bragg cell that shifts one beam at 40 mhz with respect to the other to enable direct measurements of the velocity component normal to the model surface (U). The green beams are passed through a dual Bragg cell arrangement in which one cell shifts one beam at 40 mhz and the second cell shifts the other beam at either 30 or 35 mhz. Thus, the effective frequency shift is either 5 or 10 mhz against the flow for measurement of the stream wise velocity component (U). Since the Bragg cells produce several higher order diffracted beams, beam stops are employed to allow only the strongly diffracted (40 mhz and 30/35 mhz) beams to pass through the rest of the optical system. The beams then pass through wedge prisms which allow fine adjustments of the cross-over points of the focussed beams. The four beams are then directed through beam spacers which reduce the separation to about 9 mm. At this point an option is available for the inclusion of a 2.27 x beam expander. Installation of the expander yields a smaller beam waist but precludes measurements of the V-component due to the reduced persistence time of particles in the probe volume. However, the reduced waist enables measurements of the U-component closer to the model surface. The final element of the transmission optics is a 935 mm focal length (fl) 85 mm diameter acromatic focussing lens. The collection optics are mounted on a single (vertical) axis positioning table and consist of the following elements. The first element is a 1219 mm fl 152 mm diameter receiving lens which is followed by a 3.75 x expander. The collected light is then passed through a dichroic mirror to separate out the green and blue components. Each component color is passed through optical bandpass filters and focussed onto a 0.20 mm aperture. The light of the respective components is detected by RCA 452.6 photomultiplier tubes (PMTs). The PMT signals are then amplified and cabled to the control room.

3. TRAVERSING SYSTEM

A three axis microprocessor-controlled traversing system has been custom built to accurately position the LV optical system for precision surveying of flow fields within a two foot cube (Figure 4). This traversing system is a special XYZ configuration of quality machine tool positioning tables which inherently possess high performance and repeatability (±.0001 inch), even at the extremities of the traverse range of all three axes. Position accuracy is ±.0001 inches/inch of travel. The system is capable of supporting 300 pounds of velocimeter optics. The assembly is mounted on an eight inch thick by 48" square granite base. Total system weight is 3500 pounds. It can reasonably be moved to and positioned at various facilities by means of a fork lift. No problems have developed to date because of moving it in this fashion between buildings. Three independent servo motors with linear digital encoders provide for stepping or continuous movement of the LV sampling volume along any line in the test flow. This could include complex three dimensional lines as well as sequential mapping along families of lines of many forms. Each axis can be independently programmed for a speed of .01 to 600 inches/minute with dwell times of from .001 to 64 seconds. The table can be manually or automatically controlled from the console which has a built-in microprocessor using a numerical control (NC) base high level language. Programs may be stored on and read from proms using the prom reader-programmer in the console. The commands and circuits of the microprocessor have much versatility. Therefore, remote control and automatic interlocked operation with the LV data recording system can be accomplished under control of another computer.

4. SIGNAL AND DATA PROCESSING SYSTEM

The signals from the respective PMTs are input to one or more LV frequency counter processors. These include high and low pass filters, amplifiers, Schmitt triggers, and associated signal processing electronics. They incorporate a 500 mhz clock which yields 2ns resolution. The function of a Schmitt trigger is to digitize the analog particle signals as seen by the PMT. The digital output from the

4

processor is then intc.faced to a microcomputer. During a run, up to 1,200 individual velocity realizations are stored on a floppy disc. The data is reduced and printed after the tunnel runs are completed. Oscilloscopes are used to monitor the amplified and filtered signals as well as the Schmitt trigger output during the run.

SECTION III

LASER VELOCIMETER SYSTEM

1. OPTICAL DESIGN

The LV is operated in an interference fringe mode. The fringe spacing (d) is calculated from Bragg's Law,

$$d = \frac{\lambda}{2 \sin\theta}$$

where λ = the wavelength and θ = the 1/2 angle of the interfering beams. The angle θ is determined geometrically for each component (Figure 5). When adjustments are made to the optics, the fringe spacing is rechecked. The two components (4 beams) are made to focus and cross at the same spatial location. This is carefully checked and adjusted with a microscope objective placed at the probe volume. For Gaussian beams, the diameter of the beam waist at $1/e^2$ points is given by

$$W_o = \frac{4fl\lambda}{\pi DE}$$

where fl = lens focal length, D = diameter of the input beam, and E = expansion factor. Thus when the 2.27 beam expander is utilized, the probe volume (diameter) is reduced by that factor. However, the fringe spacing is also reduced (approximately) by 2.27. For a given velocity (U)

$$U = df \text{ where (f = frequency)}$$

it can be seen that as the fringe spacing decreased the frequency increases. Therefore, with the beam expander in the system, there is a gain in the spatial resolution but a loss in the counter resolution. However, the system has been run without the beam expander for most of the data obtained during this test series.

The collection optics were oriented in a forward scatter configuration to ensure a high signal-to-noise ratio (SNR). Typical signal levels from scattered particles at low velocity were on the order

of several volts peak to peak. During the tunnel runs, however, the signal dropped to about one volt peak to peak. This drop was due to a decrease in the number of photons scattered from particles traveling at high velocity. The SNR, however, did not decrease significantly and the signal level was more than adequate for the processing electronics to yield reliable measurements.

During the initial alignment of the system, it was necessary to determine the location of the probe volume in relation to the model. The distance above the model was found by burning a small hole in a piece of mylar and measuring this distance on a scale. The traversing table readout was then set by this measurement. It was observed that from day to day during the tests, a minimal amount of optical alignment and adjustments were required.

2. BRAGG SHIFT RATIONALE

The details, functions, and applications of Bragg cells will not be generally discussed in this report. This information can be found in Reference 4.

For the signal processor to validate a velocity data point, there must be a minimum of eight cycles from the Schmitt trigger which implies that a particle passing through the probe volume has scattered light from eight fringes. In practice, 12 to 14 fringes are required because of the Gaussian profile of the laser spot at the probe volume. For the U-component in the free stream without Bragg shifting, the number of cycles is about 11. By a shift of 5 mhz against the flow, the number of cycles is about 13 and the doppler frequency is about 27 mhz. For a 10 mhz shift against the flow, there are about 16 cycles with a doppler frequency of 32 mhz. The output of the particular downmixer used for these tests has a 25 mhz low pass filter in order to eliminate modulation on the signal from the 40 mhz crystal. Therefore, it was necessary to utilize a dual Bragg cell arrangement and process the signal directly from the PMT. One Bragg cell was shifting at 40 mhz against the flow and the second cell shifting at either 30 or 35 mhz with the flow. This yielded an actual shift of either 5 or 10 mhz against the flow.

7

3. ERROR CONSIDERATIONS

a. Systematic Errors

The sources of systematic errors in the LV are the following: Bragg cell accuracy, fringe orientation, and processor resolution. The 40 mhz crystal oscillators which drive the Bragg cells have an accuracy of approximately 0.01%. The alignment of the beam crossings determines the fringe orientation with respect to the flow direction. The resulting data shows that this error is insignificant as illustrated by a near zero vector (V) in the free stream. The processor resolution is the dominant error and will now be discussed in detail.

In the free stream, the mean velocity as measured by the LV was U = 3359.2 ft/sec = 1023.89 m/s with a fringe spacing d = 50 microns. The Doppler frequency is:

$$f_{D_1} = \frac{U}{d} = \frac{1023.89 \text{ m/s}}{50 \times 10^{-6} \text{m}} = 20.478 \text{ mhz}$$

Witn a 5 mhz Bragg shift, the frequency to the signal processor is:

$$f_{p_1} = f_{Bragg} + f_{D_1} = 5 + 20.478 = 25.478 \text{ mhz}$$

and the period of the signal is:

$$\tau_{p_1} = \frac{1}{f_{p_1}} = 35.25 \text{ ns/cycle}$$

With the processor set for 5/8 comparison;

$$8\tau_{p_1} = 8 \times 35.25 \text{ ns/cycle} = 314 \text{ ns/cycle}$$

Since the processor has a clock period of 2 ns, the number of counts is:

$$\frac{314 \text{ ns}}{2 \text{ ns}} = 157 \text{ counts}$$

8

For 1 clock count error in the processor, i.e., 158 counts

$$8\tau_{p_2} = 2 \text{ ns} + 8\tau_{p_1} = 316 \text{ ns/cycle}$$

$$\tau_{p_2} = 39.5 \text{ ns/cycle}$$

now,

$$f_{p_2} = 25.32 \text{ mhz}$$

and,

$$f_{D_2} = 25.32 \text{ mhz} - 5 \text{ mhz} = 20.32 \text{ mhz}$$

thus,

$$U_2 = 1015.82 \text{ m/s} = 3332.75 \text{ ft/sec}$$

$$\Delta U = 26.45 \text{ ft/sec} = 0.8\%$$

Therefore, the fluctuating velocity resolution is about 0.8% of the free stream velocity.

In theory, the V-component at the tunnel centerline is near zero. Therefore, the particle residence time in the probe volume and the Bragg shift determine the number of cycles available to the processor. Thus, the resolution depends only on the Bragg shift. The residence time in the probe volume is:

$$T_{res} = \frac{\text{spot diam m}}{\text{velocity m/s}} = \frac{590 \times 10^{-6}}{1023.89 \text{ m/s}} = 576 \text{ ns}$$

Thus for a 40 mhz Bragg shift, the number of available cycles is:

$$\frac{576 \text{ ns}}{25 \text{ ns/cycle}} = 23.0 \text{ cycles}$$

With the processor set for 10/16 comparisons,

$$\tau_{p_1} = 25 \text{ ns/cycle and } 16\tau_{p_1} = 400 \text{ ns/cycle}$$

$$= 200 \text{ counts}$$

For a 1 clock count error,

$$16\tau_{p_2} = 402 \text{ ns/cycle} = 201 \text{ counts and}$$

$$\tau_{p_2} = 25.125 \text{ ns/cycle}.$$

Therefore,

$$\Delta\tau = 0.125 \text{ ns/cycle} = 0.199 \text{ mhz}$$

and with 50 micron fringe spacing,

$$\Delta V = 9.95 \text{ m/s} = 32.64 \text{ ft/sec}.$$

This value is the minimum velocity increment that the processor can measure for the fluctuating V-component. Obviously if the clock rate is increased, the resolution will increase proportionally for each component.

b. Random Errors

Several sources of random errors that exist in the system include, velocity bias, velocity gradients in the probe volume, tunnel and model position, and test flow condition changes during a run (or successive runs) and occasional large particles that lag the flow.

Velocity bias to a higher velocity (then the actual mean) is due to particle averaging rather than time averaging of velocity realizations. This error is usually small and there are methods available to correct for this condition (Reference 7). Velocity gradients across the probe volume in the vertical direction may become significant near the surface of

10

the model. This error could be reduced by further reducing the size
(or shape) of the probe volume. Reduction of tunnel and model position
changes during a run in regard to the velocimeter reference planes are
underway by means of mechanical fixes discussed in Section VI. The
contribution of occasional large particles to the final mean velocity
calculation is relatively insignificant due to the high data rate from
the artificial seeding.

SECTION IV

PARTICLE GENERATION

The success of any LV measurement is dependent on good SNR and the availability of an adequate number and size of scattering centers in the flow. Initially, velocity realizations were achieved from naturally occurring particulates in the flow. These particles were probably generated in the storage heater system and scattered sufficiently for LV measurements. They had a wide size distribution and a relatively low number density. Thus, the number of valid velocity realizations per second (data rates) were unacceptably low (10-20 per second in the free stream and 0.5 - 2 per second in the boundary layer). These factors, coupled with the limited facility run times dictated the use of artificial seeding. Additionally, it becomes obvious that insufficient statistical data would be available for any credible turbulence measurements.

Experiences with seeding of other wind tunnels at FDL have been most promising with an oil mist. However, solid particles in suspension in a liquid carrier or fluidized bed have been used or experimented with by various investigators (References 8, 9). Because a fluidized bed of graphite particles appeared to be a safe approach in view of the high stagnation pressures and temperatures of the Mach 6 facility, a special seeder was built in-house for this purpose. It is shown in Figure 6a. The particles were graphite with a 0.6 micron diameter. These particles were injected into the stagnation section of the tunnel just upstream of the nozzle. The seed injector (Figure 6a) had a series of slits (.005" x .025") and was positioned on the center line of the tunnel in the stagnation section. This injector was used with all succeeding seed generator configurations. It soon became evident that the high number density required to significantly increase the data rate could not be achieved without further development and improvements of the fluidizing technique in the storage reservoir as well as the particle delivery system through the injector. For expediency, the seeder was reconfigured to deliver a silicone oil mist through the injector (Figure 6c). It should be noted that fluid breakup and atomizing is initiated

by venturi action in the feed line prior to reaching the injector in the
stagnation section (Reference 10). This technique worked very well. A
high particle number density (2000 per second through the LV test volume)
and small particle size (1-2 microns estimated) were achieved. The
selection of a fluid with proper characteristics for safely seeding in
the Mach 6 tunnel is difficult because of the temperatures (650 to 800°F)
and pressures (to 2,100 psi) in the stagnation section accompanied with
the large expansion through the nozzle. The amount of seed injected into
the established flow is minimal, and under these conditions the silicon
oil worked satisfactorily. While its very low vapor pressure is an
advantage, the flash point (420°F) and auto ignition point (800°F @ 1
atmosphere of oxygen) are too low for safety with high concentrations or
liquid pooling. An accidential accumulation of a nominal amount of
seeding oil in the stagnation section after one run resulted in a flash-
over on the succeeding run which carbon coated all equipment within the
test cabin.

While further safety measures would reduce the possibility of a
recurrence of a similar incident, two substitute types of fluids are
being examined. One class is the fire resistant phosphate ester
hydraulic oils whose auto ignition points range from 1,000 - 1,300°F
although their flash points are still relatively low (400-500°F) for
this application. Two drawbacks to these fluids are relatively high
vapor pressures and increased toxicity. The other class of fluids
are halogen compounds which are thermally safe. Two of the halogen
compounds with vapor pressures below .01 mm at 80°F will be evaluated.
It should be stated that a toxic problem may exist with these under
high temperatures with minute quantities of products of dissociation.
This investigative work is being aided by chemists and toxicologists
of the Air Force's Material and Aeromedical Research Laboratories
as well as by those in industry. A major problem is inadequate data
in relation to tunnel conditions.

Calculations for determination of the required particle density for
adequate data rate follow. Since the wind tunnel nozzle diameter is

approximately 12", the cross sectional area is 113 sq in. The particle diameter is $\sim$1 micron and the particle cross section area is 4×10^{-5} in^2/particle.

In order to uniformly distribute the particles throughout the tunnel cross section, the total number of particles required is:

$$\frac{113 \text{ in}^2}{4 \times 10^{-5} \text{ in}^2/\text{part}} = 2.8 \times 10^6 \text{ particles.}$$

To have a data rate of 1000 $\frac{\text{particles}}{\text{sec}}$ @ 3000 $\frac{\text{ft}}{\text{sec}}$ requires that the distance between particles be three feet. A data rate of 3000 $\frac{\text{particles}}{\text{sec}}$ @ 3000 ft/sec requires a distance of one foot between particles. Therefore, the number of particles required per second is:

$$2.8 \times 10^6 \text{ particles } 3000 \frac{\text{ft}}{\text{sec}} \times 1 \frac{\text{particle}}{\text{ft}} \approx 8.4 \times 10^9 \text{ particles/sec.}$$

Thus, assuming uniform particle distribution in the flow, the flow rate into the seeding injector is approximately .26 cc/minute. However, to achieve an adequate data rate near the model surface, higher seeding rates are required.

SECTION V

DATA ACQUISITION AND REDUCTION

No attempt was made to do on-line data processing, because of the speed limitation of the microcomputer. Block diagrams of the processing system are shown in Figure 7. The digital raw data output of the LV processor is a representation of the time period for eight cycles of the signal from each validated photomultiplier output. Up to 1200 of these signals are first stored in the microcomputer memory and then recorded on a 5-1/4 inch floppy disc at the end of each run. This quantity is divided equally between the number of components being recorded, i.e., (for 1200 signals) 1200 for single component, 600 for two component or 400 for three component.

The maximum possible data rate for three-component data collection is about 10,000 data points per second, 15,000 per second for two components and 37,000 per second for one component. These data rates correspond to the time required to find and store individual data sets in the computer. The time window available between velocity realizations is 30 microseconds for three-components and 20 microseconds for two-components. This window is developed partly from "inhibit" circuits in the LV frequency counter processors and partly from a machine language subroutine in the microcomputer recording program. At the time data is first called for, the LV processor data "inhibit" circuits are released and the data output pulses are reset by the microcomputer program. Then a data search cycle is enabled which scans each component in ascending order looking for an acceptable data output pulse. This data pulse insures that valid data is being held and further processing of the component is inhibited. The data search cycle is repeated until a data output pulse is detected from one of the components. When this occurs each component is tested in turn for a data output pulse starting with the first component. If the data output pulse is missing from any one component, all "inhibits" are released, all data output pulses are reset and the data search cycle is resumed. If all components have data output pulses, then the data from all components is recorded. This

15

releases the "inhibits", resets the data output pulses, and causes the resumption of the data search cycle. The program for this testing and recording is in the machine language of the microcomputer. Also recorded with the data from each run is the time taken to validate that data and store it in the microcomputer memory. This time is developed with a machine language subroutine using the computer's basic 1 mhz clock. In addition, the number of data points taken in the run and the number of components being recorded are also recorded on the floppy disc. Up to 36 runs may be recorded on each disc. The program will prompt, with instructions, for continued recording into additional discs without starting the recording program anew.

The data processing for each component consists of calculating the mean velocity, the standard deviation, the ratio of the standard deviation to the mean velocity, and optionally, the creation of a velocity histogram in tabulated form. In addition, cross correlation functions are calculated for multicomponent configurations.

The data reduction process is carried out as follows. First, the time is converted into seconds and a data rate calculated. Then the raw data is converted into engineering units of velocity. Mean velocity, standard deviation, and the ratio of the two are calculated using all of the data points of a run. These values are then recalculated using only the data points which fall between two limits. These limits correspond to the mean velocity plus and minus three times the standard deviation. The cross correlation and histograms are calculated making use of these bracketed values. Histograms are made using 40 bins where the minimum bin value and delta bin are typed by the operator on demand. Optionally, all bin limits may be inserted by the operator so that bin size may be varied across the histogram.

SECTION VI

TESTING PROCEDURES AND RESULTS

The operational procedure was to set the desired stagnation pressure
and then the tunnel was put into flow. Once a stable flow field was
established, the model was injected. Before LV data was taken, the
Schmitt trigger of the LV processor was set to a threshold level just
above the background noise. LV data was then taken and the "y" values
(distance above the model) were recorded.

Only one LV data point was taken during each run because the
collection optics table had to be set manually for each "y" value.
Center line velocity measurements with the model out of the flow were
taken periodically to ensure repeatability of the data. It was noted
that the vertical model position with respect to the laser beam varied
during a run by approximately .010 inch. This change was attributed to
the heating of the model and its support system. The test procedure was
then modified to include a heat up run prior to recording the data. The
position of the LV probe volume in relation to the model surface was
then reset to compensate for the growth. The model is being thermally
isolated from its support struts to further reduce this growth problem in
future testing. It was also observed that the entire test cabin
assembly, including the model, moved about .250 inches up stream because
of thermal expansion after several minutes of tunnel running. Presently,
a slip joint is being installed in the diffuser piping to eliminate this
problem.

With the seeder in its final configuration, the procedure was to
pulse the seed while data was being taken in order to minimize the total
amount of seed injected into the flow. Velocimeter measurements near
the model surface (closer than .025 inches) required special care because
of a problem with signal conditioning and flare light from the model.
Since the doppler frequency (plus the Bragg shift) could be below 16 mhz
near the model surface, the adjustable front end filters which exist on

the signal processor were opened to 8 mhz. However, opening of the filter bandwidth could allow noise to be processed (Figure 8). Further analysis is underway to resolve this problem. During later runs, the Bragg shift was changed from 5 to 10 mhz against the flow at a slight loss of Bragg cell performance. This change apparently improved the filtering situation. The flare problem was minimized by tilting the collection optics and carefully blocking scattered light. The flat plate model geometry and location of the survey stations are shown in Figure 9. Typical velocity profiles through the boundary layer are shown in Figures 10 and 11. Two-component data was taken with a 30^0 wedge at the intersection of the plate and wedge (15.5 inches from the leading edge). The U-component data is shown in Figure 12 and the V-component in Figure 13. The cross correlation function ($\overline{U'V'}$) is shown in Figure 14 and the turbulence intensity in Figure 15. It should be mentioned that the free stream mean velocity as measured with the LV agrees very well with theory and probe measurements and is very repeatable. The LV measurements of free stream turbulence were approximately 1-1/2%. This is higher than might be expected. However, it should be noted that the facility ran without its flow straightening screens in the stagnation section for this test series. No comparative flow turbulence data is currently available for this facility configuration.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

One and two-component LV measurement in a Mach 6 High Reynolds Number Facility has been demonstrated to within .007 inches of a flat plate as well as a plate with a 30° ramp. Many of the difficulties of making LV measurements in this facility have been overcome. Results of one and two-component data are described. Three-component capability will be evaluated and verified with a cone model. The planned approach will be based on W. Yanta's work (Reference 11). Some problems still exist. They are in the areas of signal filtering, monitoring the model position, system accuracy, and data management techniques. These problems are all being addressed and should be overcome in the near future.

Several improvements to the system are planned and are presently underway. One important upgrade is the utilization of a higher performance minicomputer for increased data acquisition speed. Another planned improvement is to utilize existing backscatter collection optics with a high powered (15 watt) argon laser recently acquired by FDL. This will enable all optical components to be mounted on the computer controlled three-axis table. Thus, an entire boundary layer profile could be acquired during one tunnel run. Planned acquisition of processors with one nanosecond resolution will substantially contribute to improved accuracy of the system for high velocities. Still another modification is to utilize a newly available 13 mm beam spacer in place of the 9mm spacer. This change will eliminate the need for Bragg cells on the U-component because there will be about 22 fringes in the probe volume. The measurement resolution will be about the same for a 5/8 comparison on the processors (i.e., 0.8%) however, with 22 cycles available a 10/16 comparison may be used which would yield an accuracy of 0.4%. In addition with a one nanosecond clock, this could be further improved to 0.2% resolution in the free stream.

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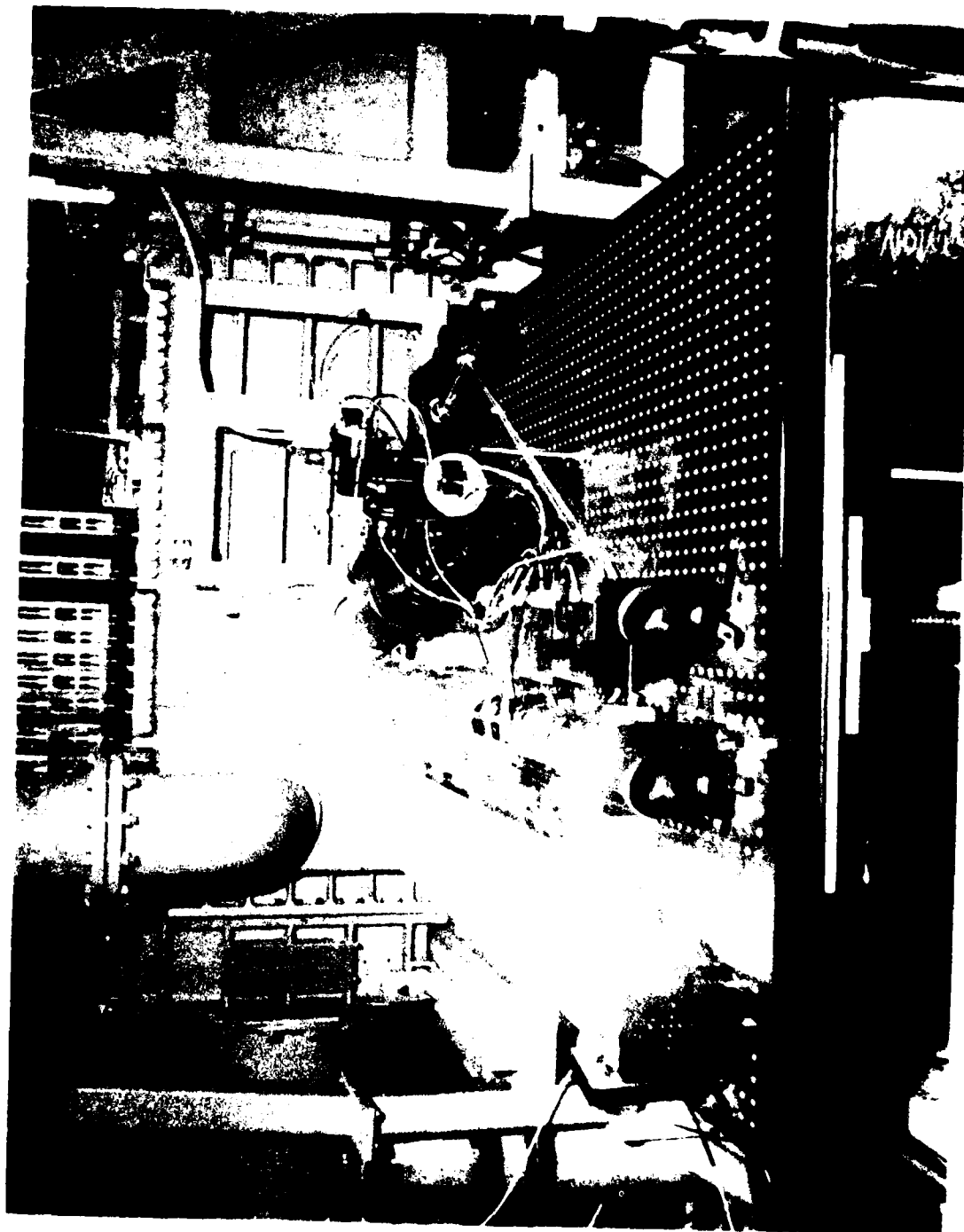
Figure 1. Three-Component Three-Color Velocimeter

a. Mach 6 Facility

b. Flat Plate

Figure 2. Test Installation
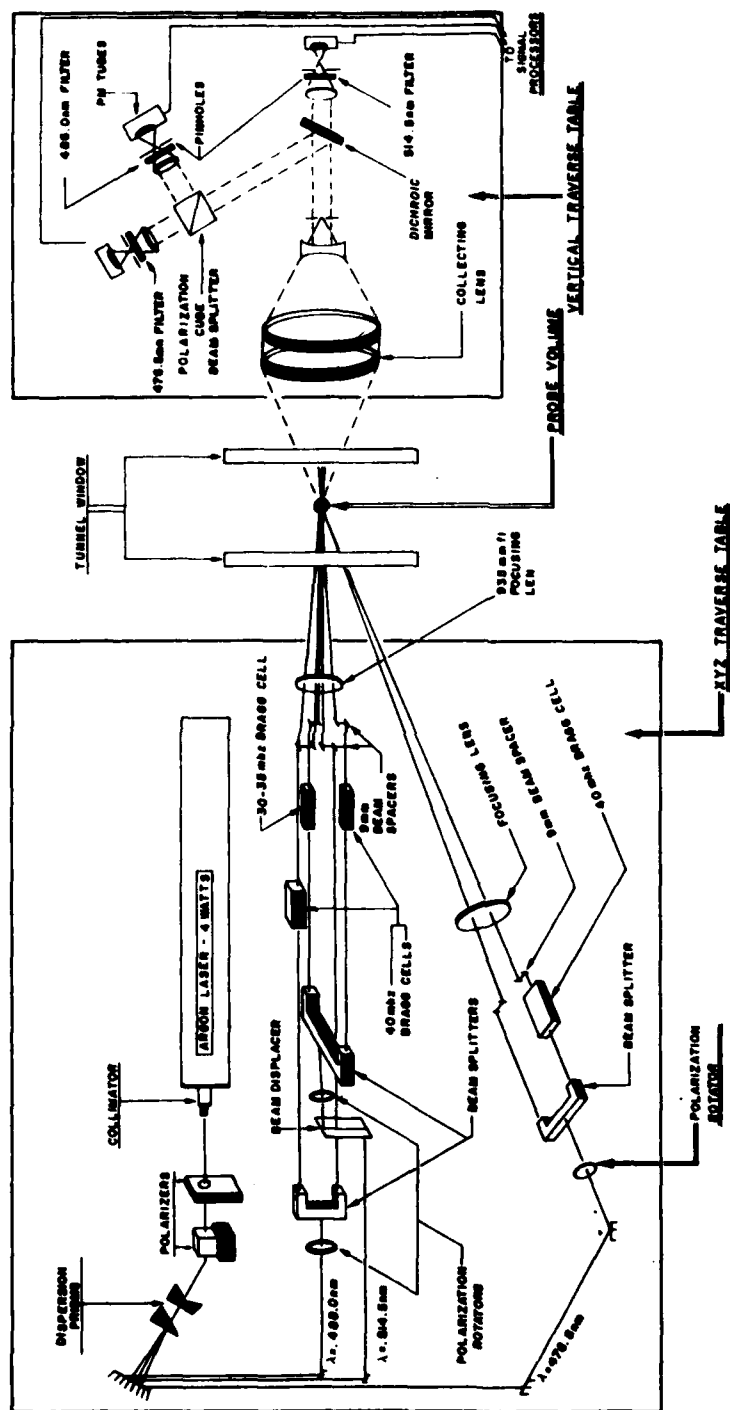
Figure 3.   Velocimeter Diagram in Forward Scatter Mode

a. Control Console and Drive Assembly

b. XYZ Drive Table
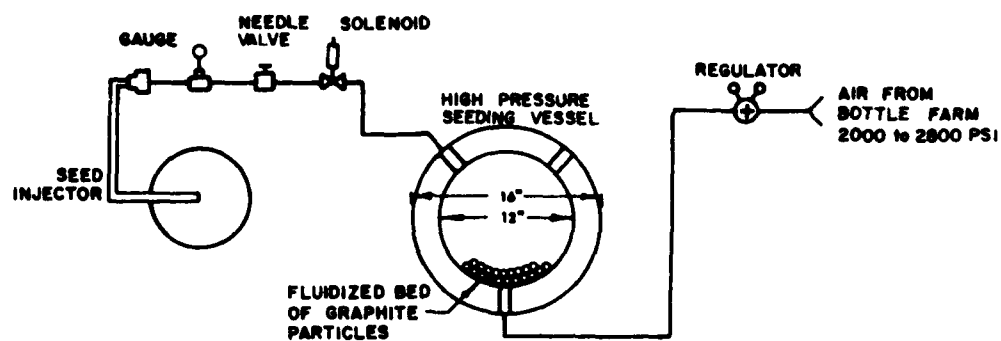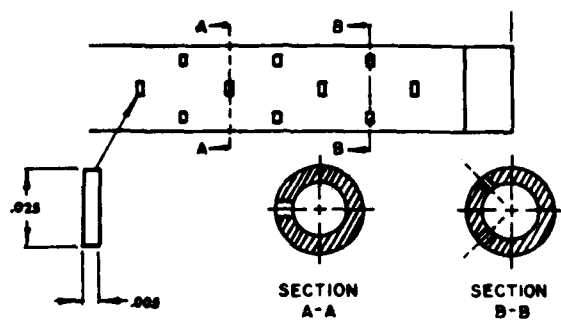
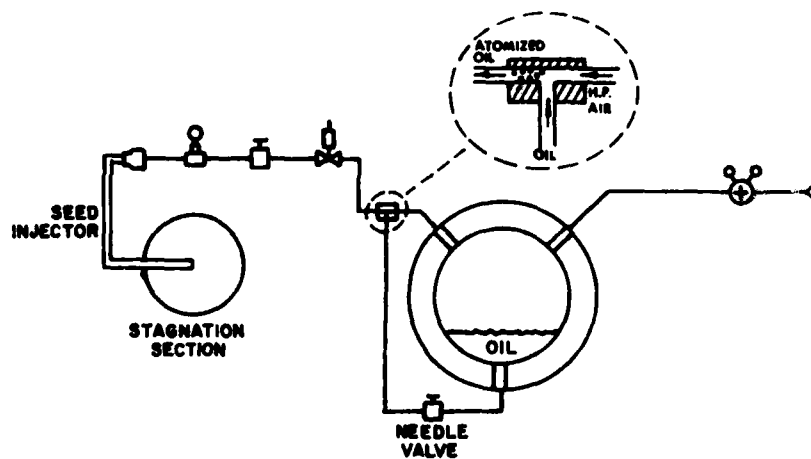Figure 4. XYZ Computer Controlled Traverse Table

$\theta = \arctan\left(\frac{X}{Y}\right)$

$d = \frac{\lambda}{2\sin\theta}$

$W_o = \frac{4}{\pi} \cdot \frac{fl \cdot \lambda}{D}$
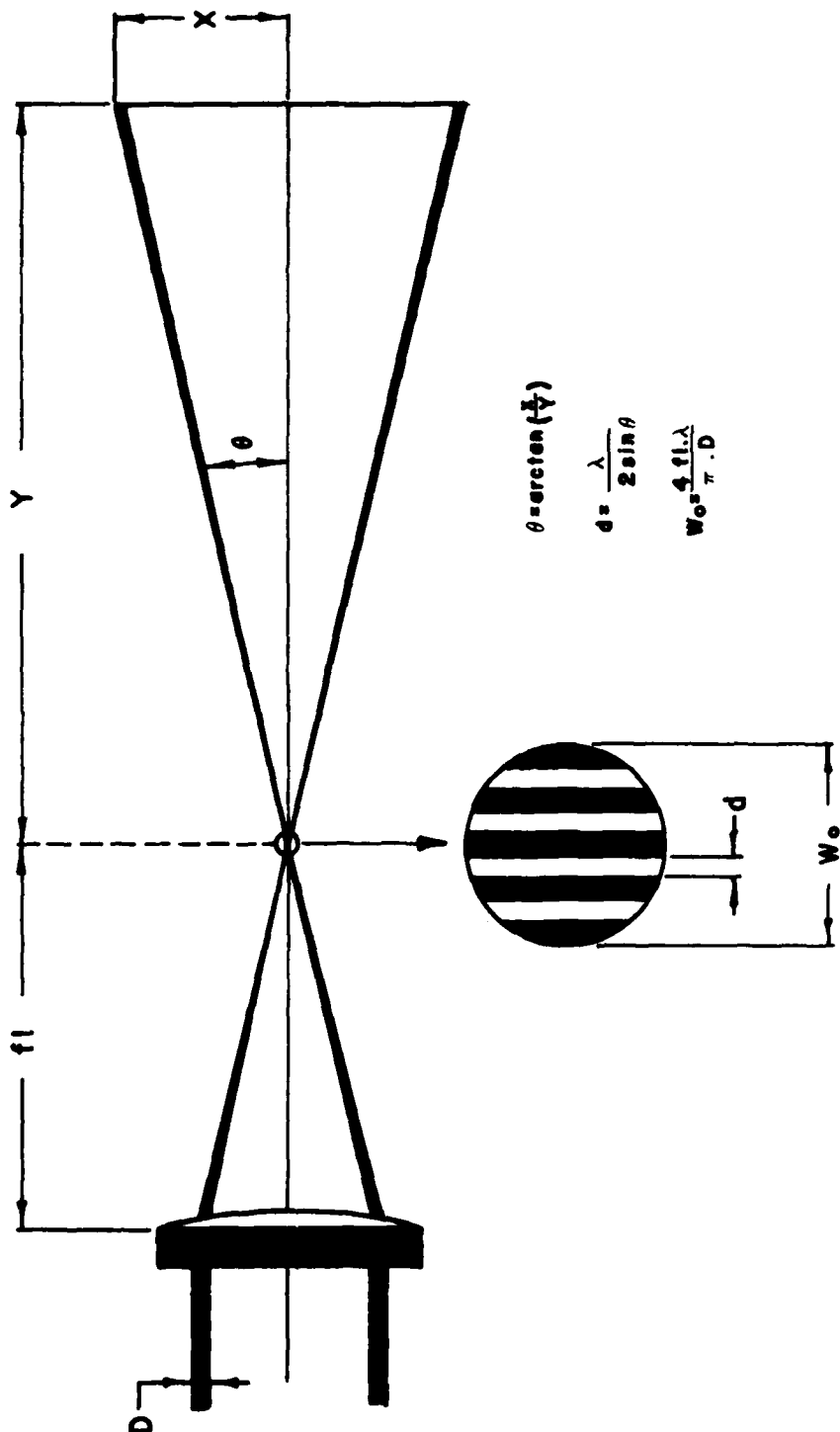
Figure 5. Beam and Probe Volume Geometry

a. Fluidized Bed Seeder

b. Seeding Injector

c. Atomized Oil Seeder

Figure 6.   Seeding Arrangements
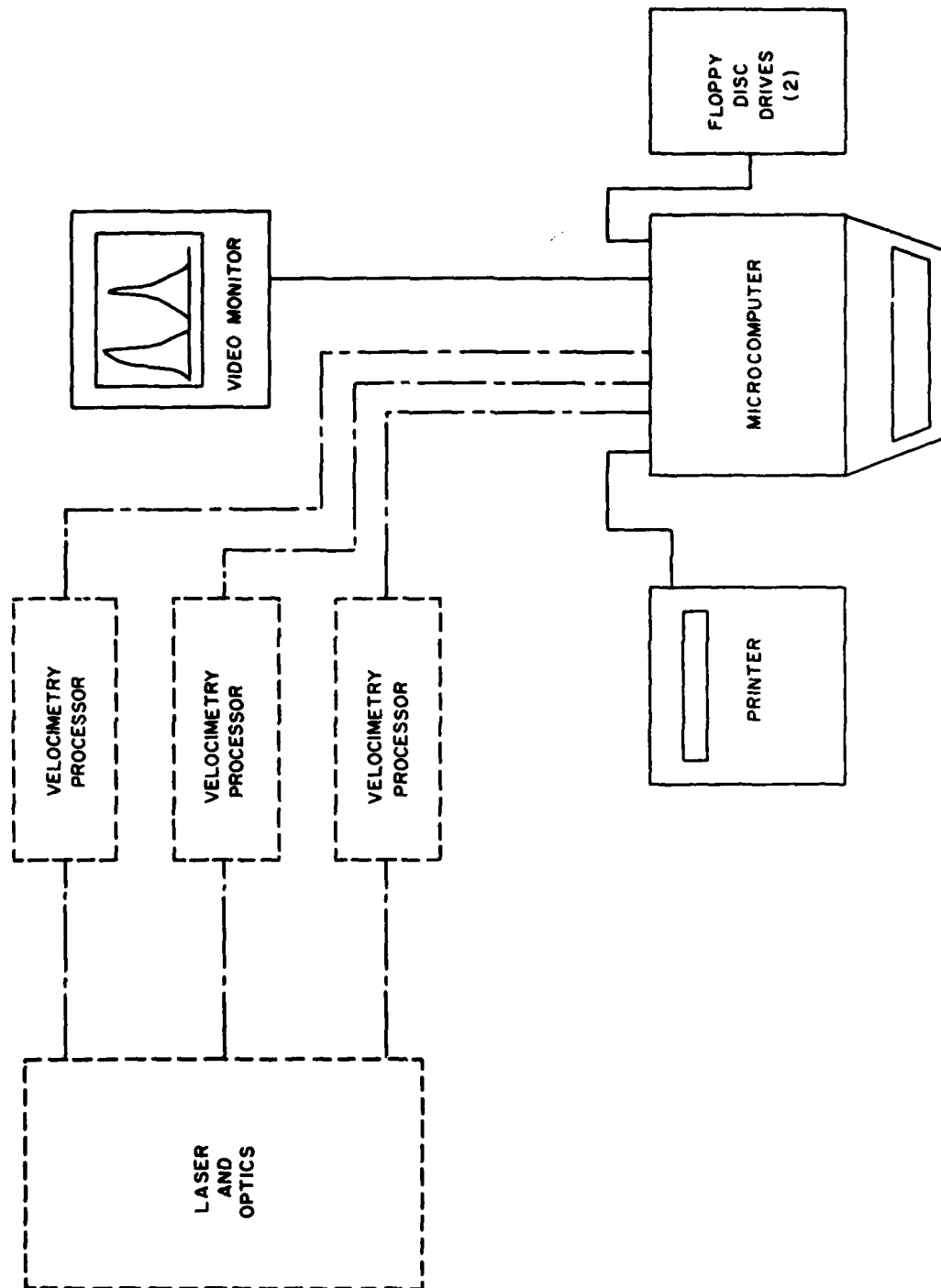
Figure 7.   Block Diagram of LV Data System
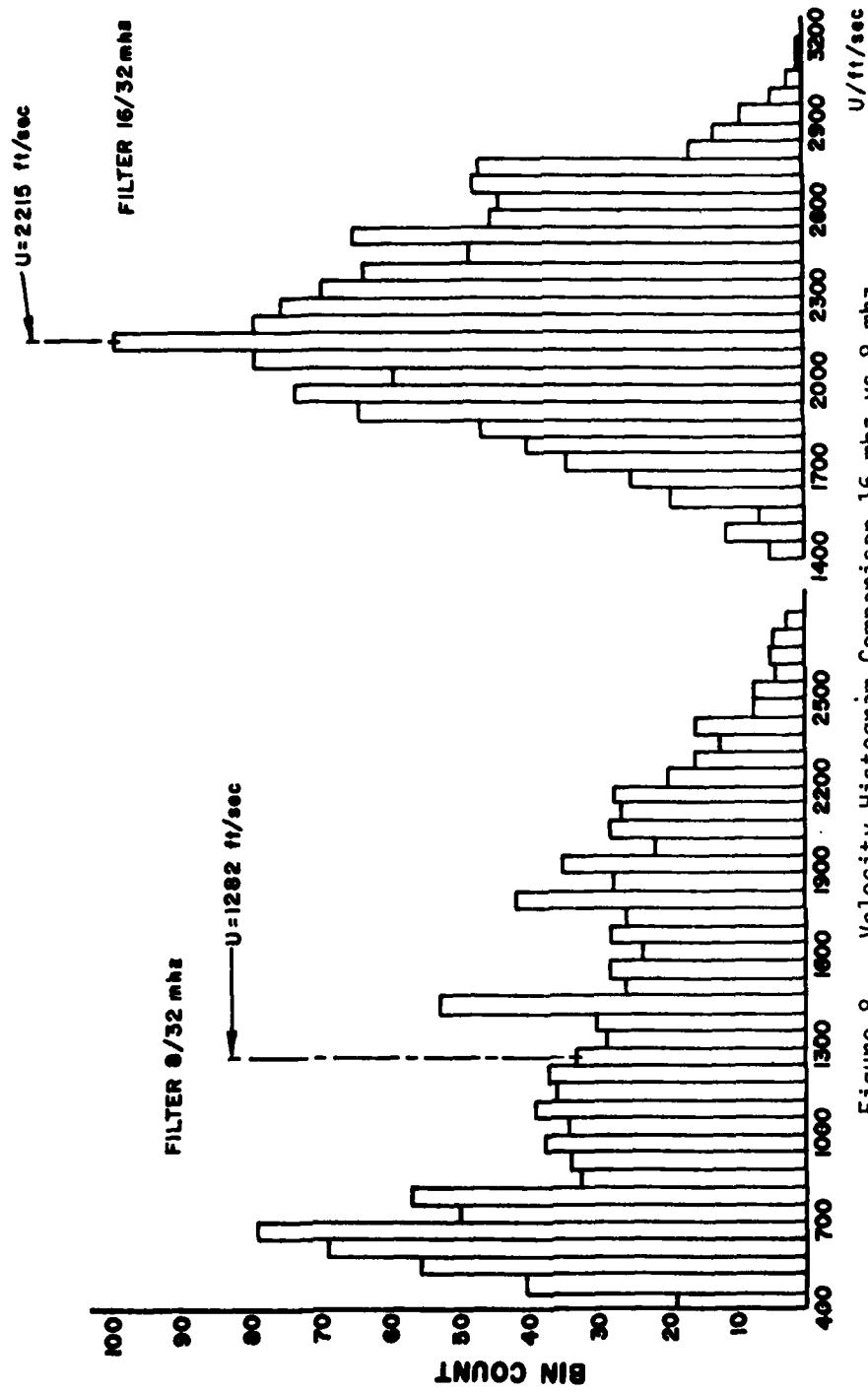
Figure 8.   Velocity Histogram Comparison-16 mhz vs 8 mhz

STATION
17.15

STATION
12.00

.762"

A. Flat Plate

18.5"

10°

STATION
15.50

30°

B. Flat Plate and Ramp
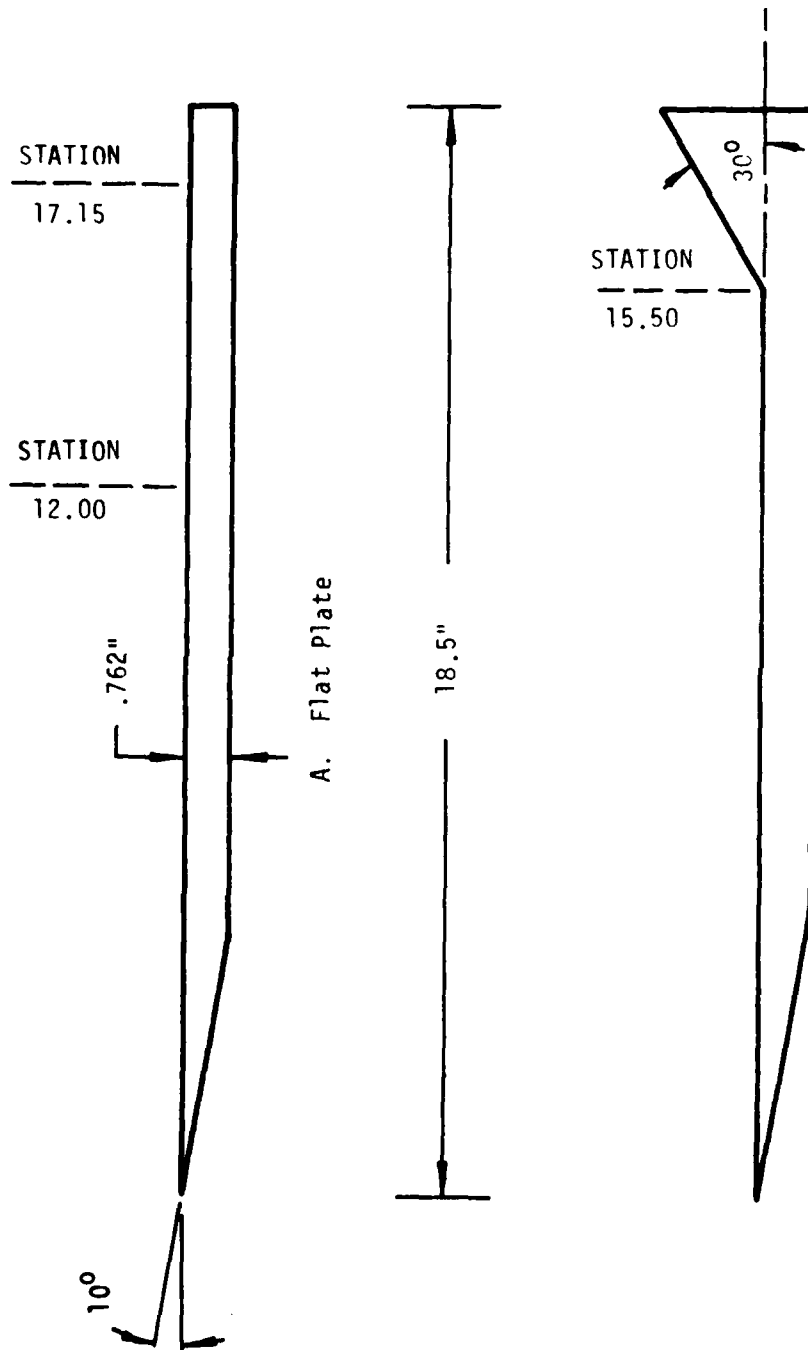
Figure 9. Model and Survey Station Geometry
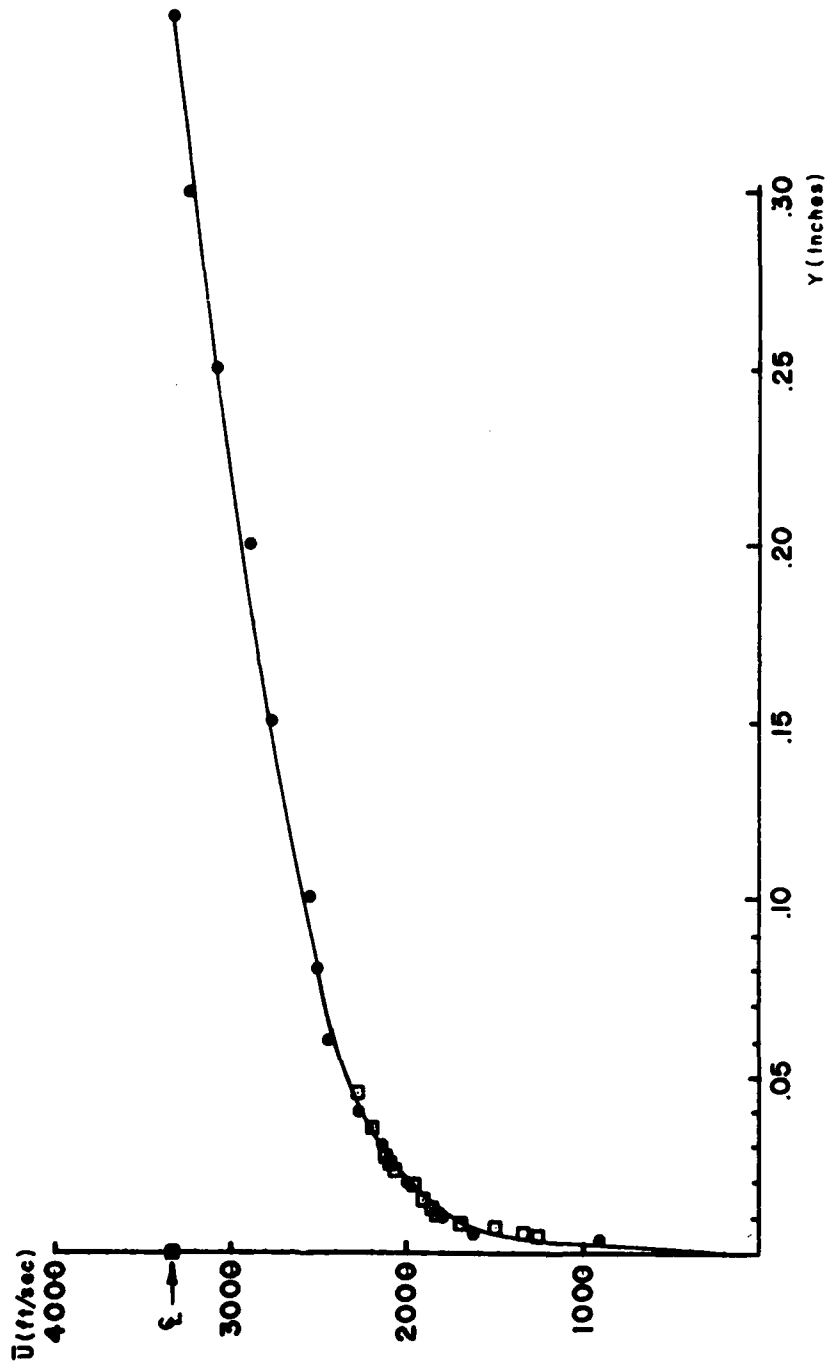
Figure 10.   Velocity Profile at 17.15 Inches from Leading Edge
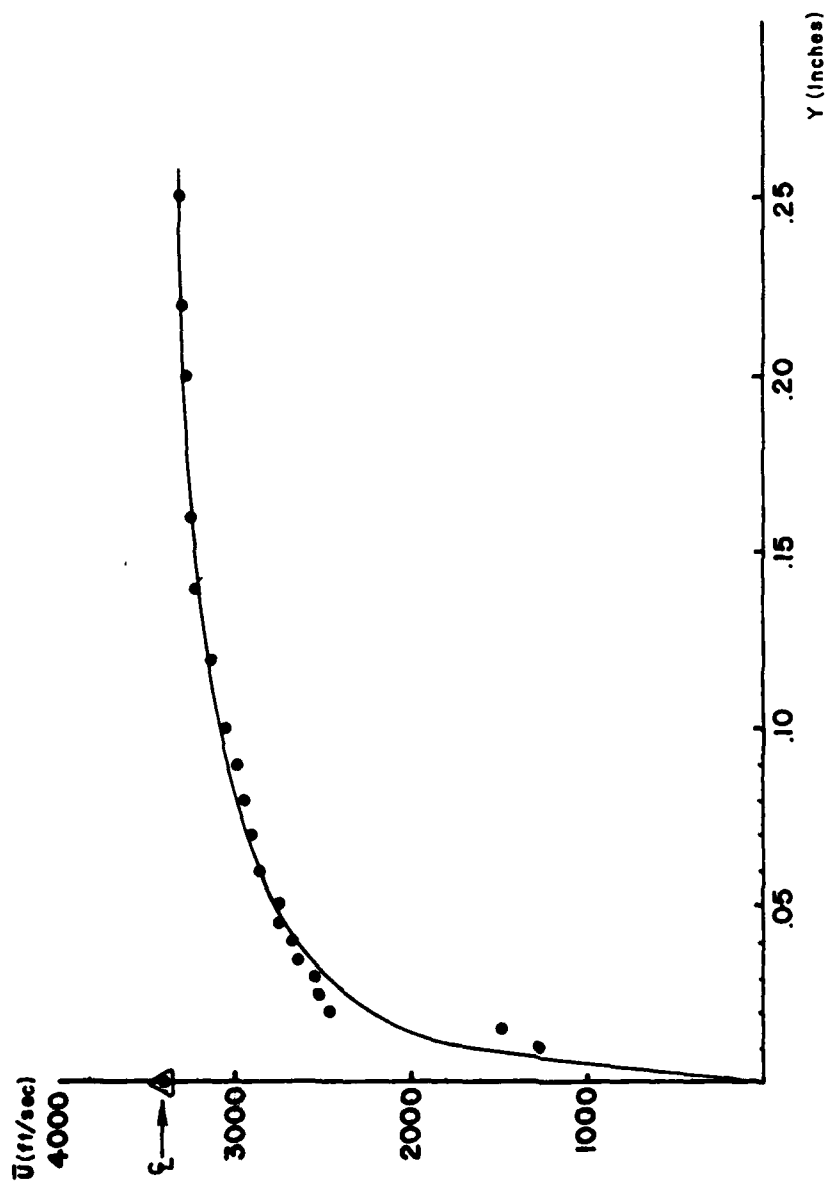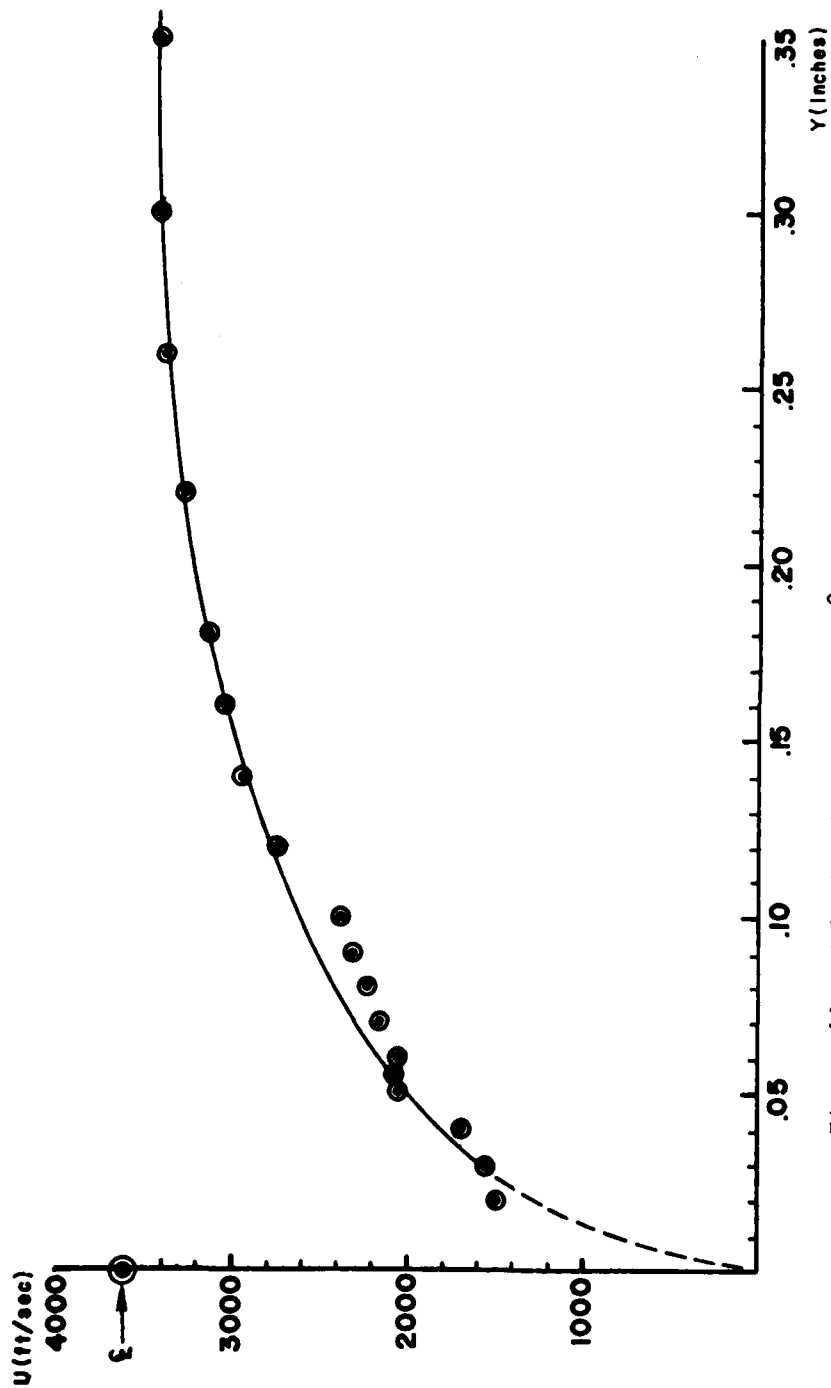
Figure 11.   Velocity Profile at 12 Inches from Leading Edge

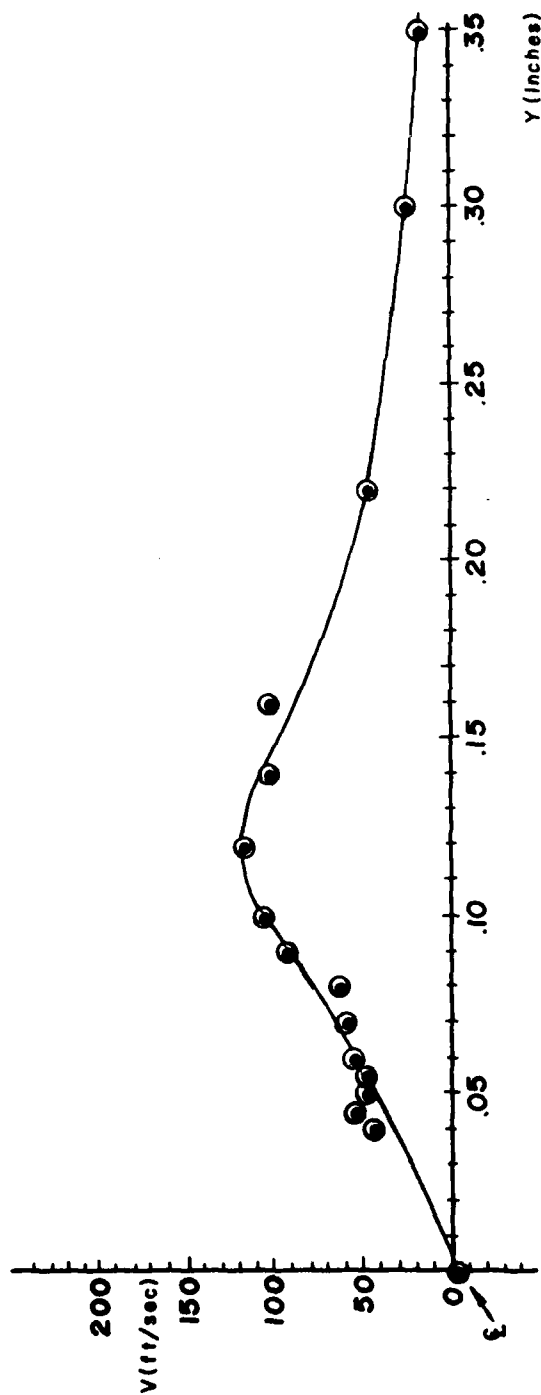Figure 12.   Velocity Profile with 30° Ramp - U-Component at 15.5 Inches from Leading Edge

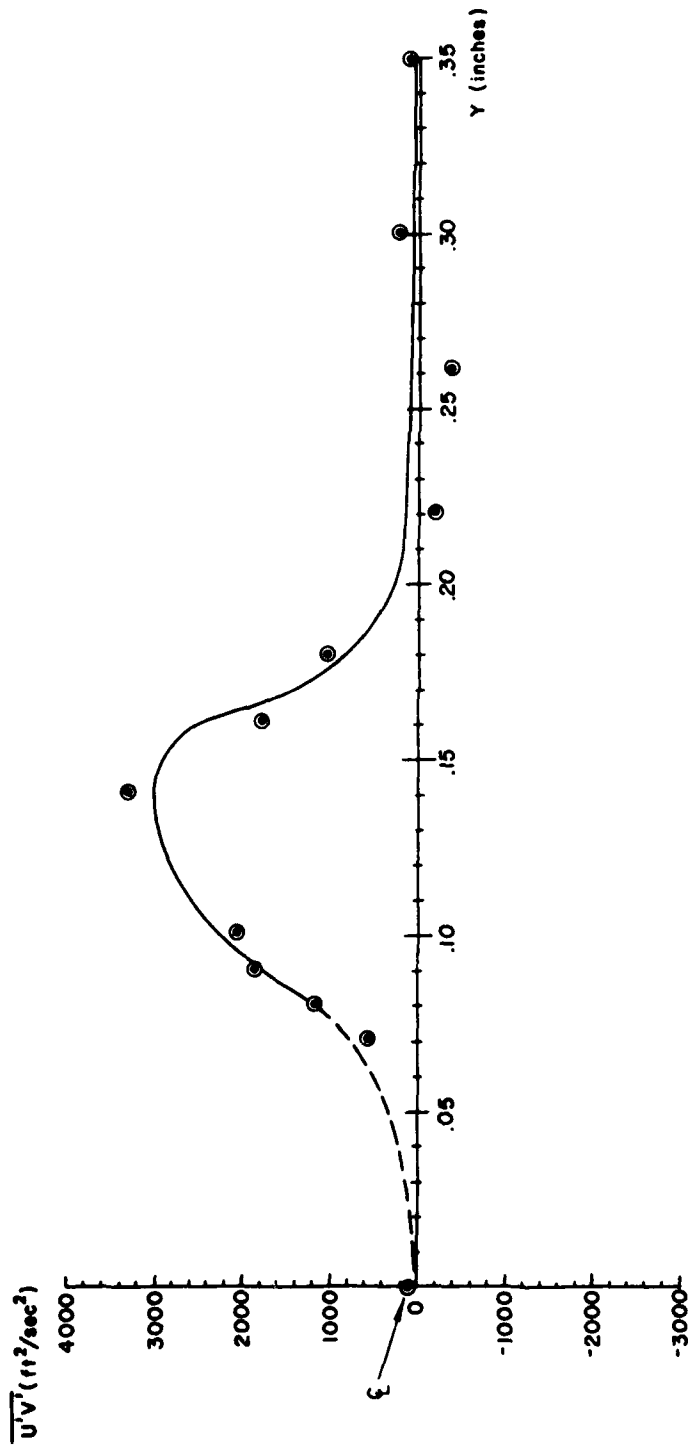Figure 13. Velocity Profile with 30° Ramp - V-Component at 15.5 Inches from Leading Edge

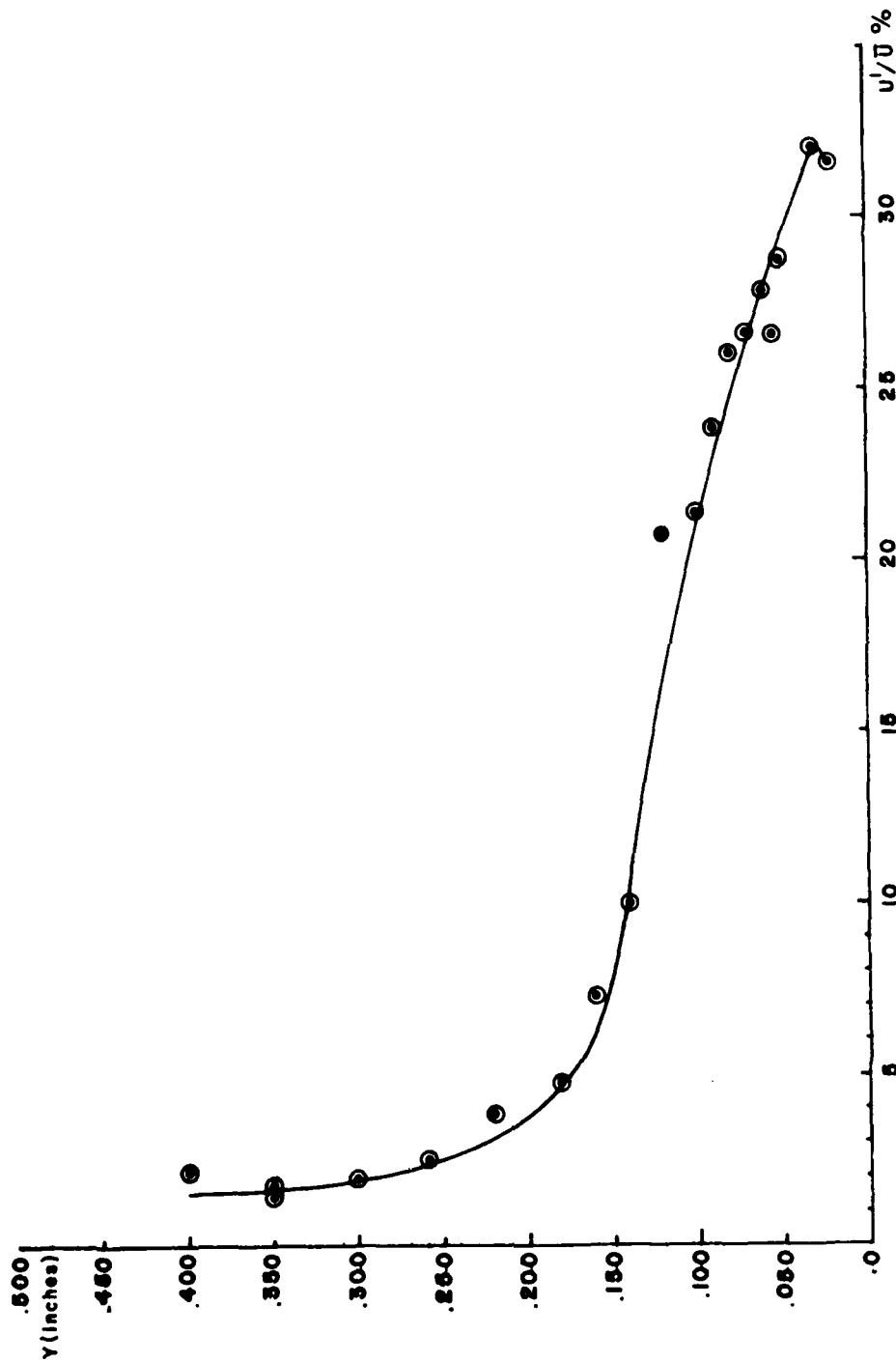Figure 14. Cross Correlation Function $\overline{U'V'}$ With 30° Ramp at 15.5 Inches from Leading Edge

Figure 15. Turbulence Profile at 15.5 Inches from Leading
Edge

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8